

## VII. Chassigny

Dunite, ~4 kg.  
*seen to fall*

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**Figure VII-1.** The Chassigny meteorite at the Paris Museum National d'Histoire Naturelle. Piece weighs 215 grams. Photo kindly provided by Claude Perron.

### **Introduction**

On October 3, 1815, at about 8:00 a.m., a stone, or perhaps several, fell after detonations near the village of Chassigny on the plateau of Langres in the province of Haute-Marne, France (Pistollet, 1816; Graham *et al.*, 1985) (figure VII-1). The possible significance of the coincidence of the fall day with that of Zagami has been discussed by Treiman (1992).

Chassigny contains mostly olivine and is thus classified as a dunite. Because of its young age, similar oxygen isotopes and REE pattern, this meteorite has been grouped with the nakhlites and the rest of the Martian meteorites. It also has a similar  $^{142}\text{Nd}$  anomaly to that of the nakhlites.

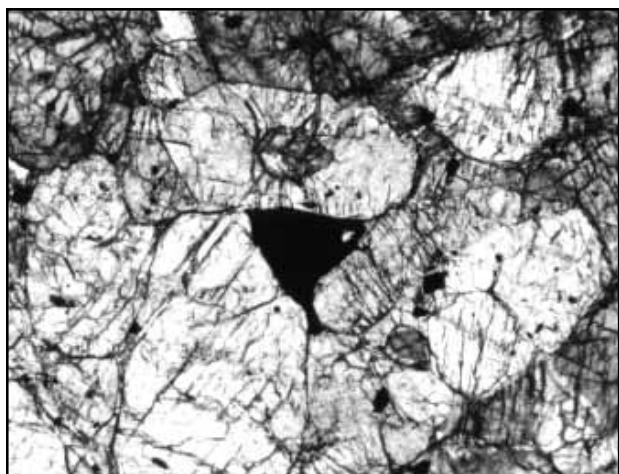
Chassigny is important because it is found to contain noble gasses that are entirely different from those in EETA79001 glass and the Martian atmosphere (Ott,

1988, Ott and Begemann, 1985). Presumably this rare-gas component is from the Martian mantle (see section on Other Isotopes).

Although Brachina was originally classified as a chassignite, Nehru *et al.* (1983) and Clayton and Mayeda (1983) showed that the brachinites are a different class of meteorites.

### **Petrography**

Chassigny is a dunite with rare poikilitic, Ca-rich, pyroxenes containing lamellae of exsolved Ca-poor pyroxene (Johnson *et al.*, 1991) (figure VII-2). The olivine ( $\text{Fo}_{88}$ ) often has melt inclusions (Floran *et al.*, 1978, Mason *et al.*, 1975). Prinz *et al.* (1974) gives the mode as 91.6 % olivine, 5 % pyroxene, 1.7 % plagioclase, 1.4 % chromite, and 0.3 % melt inclusions. Floran *et al.* (1978) reported minor alkali feldspar,



**Figure VII-2.** Photomicrograph of thin section of Chassigny. Field of view 2.2 mm. Section #624-4 loaned by Smithsonian. Note melt inclusion in olivine and large chromite grain.

chlorapatite, marcasite, pentlandite, troilite (?), ilmenite, rutile and baddeleyite as accessory minerals. Wadhwa and Crozaz (1995) reported poikilitic pigeonite in Chassigny and determined the trace element compositions of the phases.

Igneous chromite contains substantial  $\text{Fe}^{+3}$  (Floran *et al.* 1978) proving crystallization under oxidizing conditions.

Interstitial feldspar, with a range of composition from sanidine to labradorite was a late phase to crystallize.

Magmatic melt inclusions found in olivine range in size from the optical limit up to 190 microns (figure VII-2). These inclusions are found to include hydrous kaersutitic amphibole (Floran *et al.*, 1978), high and low-Ca pyroxene, chlorapatite, troilite, chromite, pentlandite and alkali feldspar-rich glass.

Shock features were studied by Sclar and Morzenti (1971) and Floran *et al.* (1978) who reported planar features in olivine.

## Mineral Chemistry

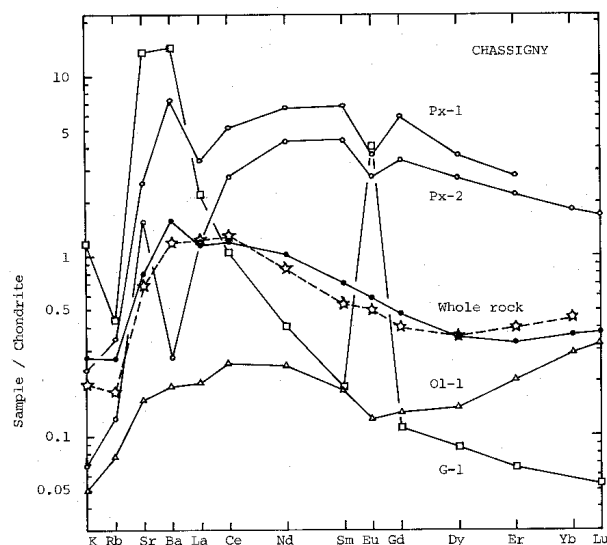
**Olivine:** Olivine is  $\text{Fo}_{68}$ , which is relatively iron-rich for a cumulate (Prinz *et al.*, 1974). Olivine appears to be in equilibrium with pyroxene. Smith *et al.* (1983) carefully determined Ni, Ca, Mn, Cr and other minor elements in olivine. The relatively high CaO (0.17-0.26%) reported by Smith *et al.* seems to indicate that this rock did not form in a “plutonic” environment.

Nakamura *et al.* (1982c) determined trace elements in mineral separates including an olivine separate (figure VII-3).

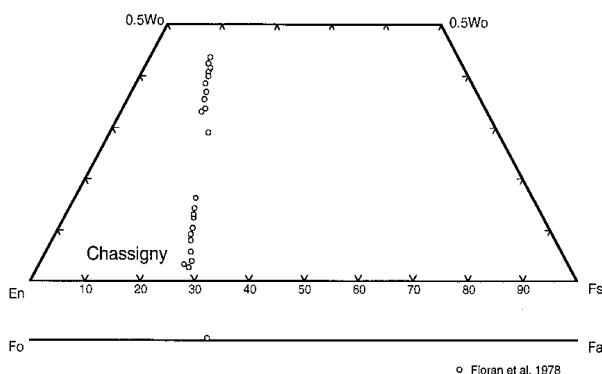
**Chromite:** Tschermak (1885) reported distinct octahedrons of chromite. According to Floran *et al.* (1978), chromite was the first phase to crystallize (it is found as inclusions in olivine) and continued throughout the crystallization sequence. Floran *et al.* made the important observation that this chromite contained substantial  $\text{Fe}^{+3}$ .

**Pyroxene:** Poikilitic pyroxene grains consist of a Ca-rich host ( $\text{Wo}_{33}\text{En}_{49}\text{Fs}_{17}$ ) with exsolved Ca-poor ( $\text{Wo}_3\text{En}_{68}\text{Fs}_{28}$ ) as thin lamellae on the (011) plane. Pyroxene is unzoned and appears to be in equilibrium with the olivine (figure VII-4). Virtually all pyroxene in one thin section occurs as a single poikilitic grain 6.4 mm in length (Floran *et al.*, 1978). However, Harvey and McSween (1994) have reported cumulate orthopyroxene in Chassigny and Wadhwa and Crozaz (1995) reported poikilitic pigeonite. Floran *et al.* (1978) reported trace element analyses for pyroxenes and these are compared with those of other Martian meteorites in figure 3 of Smith *et al.* (1983).

**Plagioclase:** Mason *et al.* (1975) determined the plagioclase composition to be  $\text{An}_{32}\text{Ab}_{64}\text{Or}_4$ . Floran *et al.* reported  $\text{An}_{32}\text{Ab}_{64.3}\text{Or}_{3.7}$ .



**Figure VII-3.** Composition diagram for mineral separates and whole rock samples of Chassigny meteorite. This is figure 1 in Nakamura *et al.* (1982b). The dashed line is data for bulk rock from Mason *et al.* (1976).



**Figure VII-4.** Pyroxene composition diagram for Chassigny. Data replotted from Floran et al. (1978).

**Potassium feldspar:** Interstitial potassium feldspar is found as 100-300 micron grains  $\text{Or}_{47.2}\text{Ab}_{47.8}\text{An}_{5.0}$ .

**Biotite:** Johnson *et al.* (1991) discovered biotite in Chassigny and found that it contained 2.3 % F and 0.4 % Cl. Watson *et al.* (1994) found 0.5 wt % H<sub>2</sub>O in the biotite with heavy D/H.

**Kaersutite (Ti-rich amphibole):** Floran *et al.* (1978) reported pleochroic amphibole (up to 75 microns) as a “conspicuous constituent” of the larger melt inclusions. Floran *et al.* reported H by ion microprobe. Johnson *et al.* (1991) reported that kaersutite contained 0.5 % F and 0.1 % Cl. Watson *et al.* (1994) determined the D/H ratio and water content of kaersutite grains in Chassigny by ion probe.

**Baddeleyite:** Floran *et al.* (1978) report the composition of a baddeleyite grain found adjacent to rutile.

**Apatite:** The apatite in Chassigny contains 3.6 % Cl (Floran *et al.* ). Wadhwa and Crozaz (1995) determined the REE content of chlorapatite.

**Sulfides:** Analyses of three different sulfides (troilite, marcasite, pentlandite) have been reported by Floran *et al.* (1978). One grain of pentlandite was found to contain 13 % Cu.

## Whole-rock Composition

Early analyses were performed by Vauquelin (1816) and Damour (1862). Prinz *et al.* (1974) noted that Chassigny is iron-rich for a cumulate dunite. Mason *et al.* (1975), Boynton *et al.* (1976), and Burghelle *et al.* (1983) reported complete analyses (table VII-1)(figure VII-5). Nakamura *et al.* (1982c) reported

REE for 'whole rock' and 'mineral' separates (figure VII-3) and confirmed the data of Mason *et al.* for the bulk sample.

Chassigny has relatively high Ni (400 ppm), Co (120 ppm), Ir (~2 ppb) and Os (1.8 ppb) (table VII-1). In addition to the data table, Curtis *et al.* (1980) determined 6.3 ppm B for Chassigny. Gibson *et al.* (1985) determined 360, 440, 300, 330 ppm S on different splits. Burgess *et al.* (1989) studied the temperature release of S.

Karlsson *et al.* (1992) found 1020 ppm H<sub>2</sub>O.

## Radiogenic Isotopes

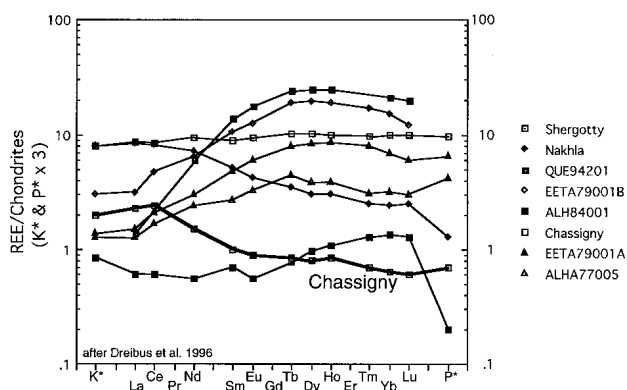
Lancet and Lancet (1971) reported a K-Ar age for Chassigny of  $1.39 \pm 0.17$  Ga. Bogard and Nyquist (1979) produced a  $^{39}\text{Ar}/^{40}\text{Ar}$  age of 1.2 - 1.4 Ga. Jagoutz (1996) determined an age of  $1.362 \pm 0.062$  Ga by Sm-Nd (figure VII-6).

## Cosmogenic Isotopes and Exposure Ages

Lancet and Lancet (1971) reported cosmic-ray exposure ages of  $9.4 \pm 0.3$  Ma for  $^3\text{He}$ ,  $7.6 \pm 0.2$  Ma for  $^{21}\text{Ne}$  and  $6.7 \pm 0.6$  for  $^{38}\text{Ar}$ . Bogard *et al.* (1984b) calculated an exposure age of about 10 Ma. Using new production rates, Bogard (1995) calculated 12 Ma from  $^{21}\text{Ne}$  data and 10 Ma from  $^{38}\text{Ar}$  data for Chassigny.

## Other Isotopes

Clayton and Mayeda (1983, 1996) reported the oxygen isotopes for Chassigny (figure I-2). Karlsson *et al.* (1992) found that the oxygen isotopes in water released from Chassigny was enriched in  $^{17}\text{O}$ , indicating that the past hydrosphere on Mars was from a different



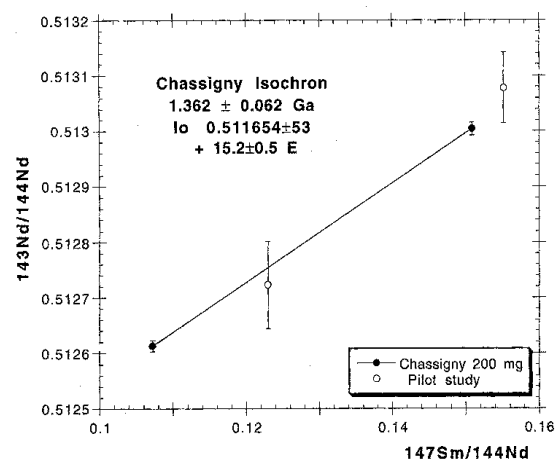
**Figure VII-5.** Chondrite normalized REE diagram for Martian meteorites including Chassigny (after Dreibus *et al.*, 1996).

Table VII-1. Chemical analyses of Chassigny.

Treiman 86		Burghelle 83	Jerome 70	McCarthy 74	Jeremine 62	D'yako-60	Boynton 76	Jerome 70	Mason 75	Nakamura	Warren87	Lancet 71
weight	0.1-0.2 g			2.1 g		.458 g				see figure	ave.	
SiO <sub>2</sub> %		38.16 (de)	37.3 (a)	37.01 (c)	36.79	37.44					37.44	
TiO <sub>2</sub>		0.1 (de)		0.07 (c)	n.d.	0.08	0.15 (d)					
Al <sub>2</sub> O <sub>3</sub>		0.69 (de)	0.47 (a)	0.36 (c)	1.17	1.07	0.64 (d)				0.64	
FeO		27.1 (de)	26.78 (a)	27.45 (c)	27.58	26.55	25.7 (d)				27.27	
MnO		0.526 (de)	0.55 (a)	0.53 (c)	0.25	0.74	0.51 (d)				0.537	
CaO		0.6 (de)	0.75 (a)	1.99 (c)	0.6	0.52	0.71 (d)				0.88	
MgO		31.6 (de)	32.7 (a)	32.83 (c)	31.95	32.17	30.2 (d)				31.83	
Na <sub>2</sub> O		0.128 (de)	0.13 (a)	0.15 (c)	0.27	1.09	0.114 (d)				0.125	
K <sub>2</sub> O		0.041 (de)	0.04 (a)	0.03 (c)	0.16	0.07	0.038 (d)					0.054 (j)
P <sub>2</sub> O <sub>3</sub>		0.058 (de)		0.04 (c)	0.11	0.07						
sum		<b>99.003</b>	<b>98.72</b>	<b>100.46</b>	<b>98.88</b>	<b>99.8</b>						
Li ppm		1.3 (de)										
C		847 (de)										
F		14.7 (de)										
S		118 (de)										
Cl		34 (de)										
Sc		5.4 (de)	8 (b)				4.8 (d)	5.58 (d)			5.9	
V			50 (b)				34 (d)				42	
Cr		4297 (de)	4500 (b)			6700	3763 (d)	4790 (d)			5100	
Co		126 (de)	100 (b)	5700 (c)	5300		124 (d)	140.6 (d)			123	
Ni	450 (e)	480 (de)	475 (b)				400 (d)				452	
Cu		2.6 (de)	<3 (b)									
Zn	69 (e)	74 (de)									72	
Ga		0.7 (de)									0.7	
Ge	0.011 (e)											
As		0.008 (de)										
Se	0.037 (e)											
Br	0.11 (e)	0.066 (de)										
Rb	1.05 (e)											
Sr			<5 (b)						0.4 (f)	0.47 (i)	0.09	
Y			<10 (b)						7.2 (f)	7.3 (i)		
Zr									0.64 (f)			
Nb									1.5 (f)			
Mo									0.32 (f)			
Pd ppb	<.15 (e)											
Ag ppb	2.6 (e)											
Cd ppb	14 (e)											
In ppb	3.9 (e)											
Sb ppb	0.87 (e)											
Te ppb	50 (e)											
I ppm		<0.01 (de)										
Cs ppm	0.037 (e)											
Ba			8 (b)						7.1 (f)	3.6 (i)		
La		0.59 (de)					0.6 (e)		0.39 (f)	0.36 (i)	0.53	
Ce									1.12 (f)	0.88 (i)		
Pr									0.13 (f)			
Nd		0.7 (de)							0.54 (f)	0.6 (i)		
Sm		0.16 (de)					0.14 (e)		0.11 (f)	0.133 (i)	0.137	
Eu		0.52 (de)					0.045 (e)		0.038 (f)	0.045 (i)	0.045	
Gd									0.11 (f)	0.13 (i)		

	Treiman 86	Burghele 83	Jerome 70	McCarthy 74	Jeremine 62	D'yako- 60	Boynton 76	Jerome 70	Mason 75	Nakamura	Warren87	Lancet 71
weight	0.1-0.2 g		2.1 g				.458 g			see figure	ave.	
Tb		0.04 (d,e)							0.02 (f)			
Dy		0.27 (d,e)							0.12 (f)	0.11 (i)		
Ho		0.058 (d,e)							0.03 (f)			
Er									0.09 (f)	0.07 (i)		
Tm												
Yb		0.12 (d,e)				0.1 (e)			0.1 (f)	0.08 (i)	0.107	
Lu		0.018 (d,e)				0.012 (e)				0.013 (i)	0.015	
Hf		<0.1 (d,e)										
Ta		<0.02 (d,e)										
W ppb		46 (d,e)										
Re ppb	0.054 (e)			Birk 94								
Os ppb	1.36 (e)			0.0711								
Ir ppb	1.85 (e)	2.4 (d,e)		1.796							1.4	
Au ppb	0.56 (e)	1 (d,e)				6 (d)					2.1	
Tl ppb	3.7 (e)					6 (d)					0.8	
Bi ppb	0.37 (e)											
Th ppm		<0.2 (d,e)						0.057 (f)				
U ppm	0.0149(e)	<0.1 "(d,e)"						0.021 (f)				

technique: a) semi-micro wet chem., b) emission spec., c) XRF, d) INAA, e) RNAA, f) spark source Mass spec., (h) B = 6.3 ppm, Curtis 1980; (i) calculated from figure 1; (j) radiation counting



**Figure VII-6.** Sm-Nd isochron diagram for Chassigny from Jagoutz (1996), LPS XXVII, page 598.

reservoir than the lithosphere. Romanek *et al.* (1996) reported additional data for oxygen isotopes in Chassigny using a newly developed laser-fluoridation technique.

Watson *et al.* (1994) reported the deuterium contents of hydrous amphiboles and one biotite in Chassigny. However, Leshin *et al.* (1996) found that the  $\delta D$  for water released from bulk samples of Chassigny was “indistinguishable from typical terrestrial values” (figure VII-7).

Jagoutz (1996) has reported a large  $^{143}\text{Nd}/^{144}\text{Nd}$  anomaly in Chassigny, which implies that the reservoir from which Chassigny was formed was depleted in light REE as early as 4.5 Ga (see also Harper *et al.*, 1995).

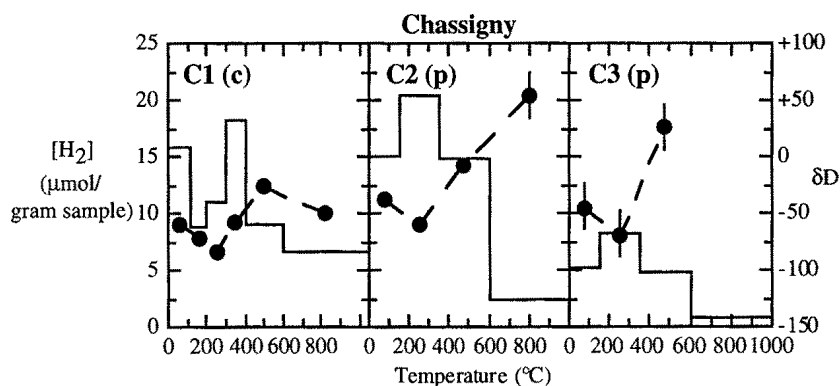
Birk and Allègre (1994) have studied the Re-Os isotopic systematics of Chassigny. The Os isotopic composition was found to be chondritic.

The carbon and nitrogen content and isotopic composition has been reported by Wright *et al.* (1992).

Chassigny contains trapped noble gases with isotopic ratios similar to solar abundances (Ott, 1988). It seems to lack the noble gas component of the current Martian atmosphere (figure VII-8).

### Extra-terrestrial Weathering

Wentworth and Gooding (1994) reported trace amounts of Ca-carbonate, Ca-sulfate and Mg-carbonate in cracks inside Chassigny. They emphasize “that water-precipitated salts in Chassigny comprise unmistakable

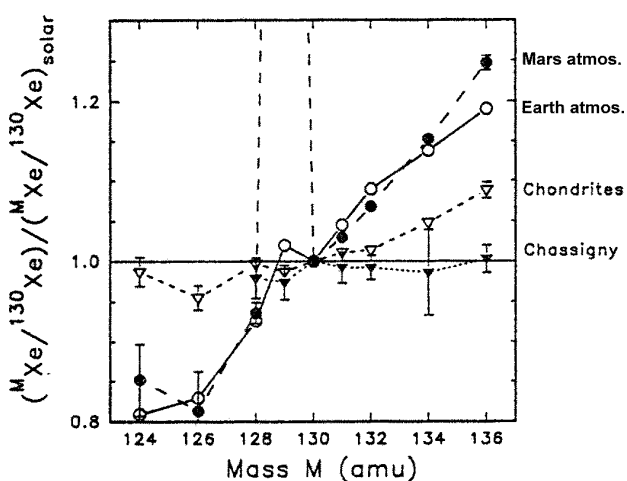


**Figure VII-7.** Hydrogen isotope composition of water released by stepwise heating of Chassigny meteorite. This is a copy of figure 4 in Leshin et al. (1996), GCA 60, 2641.

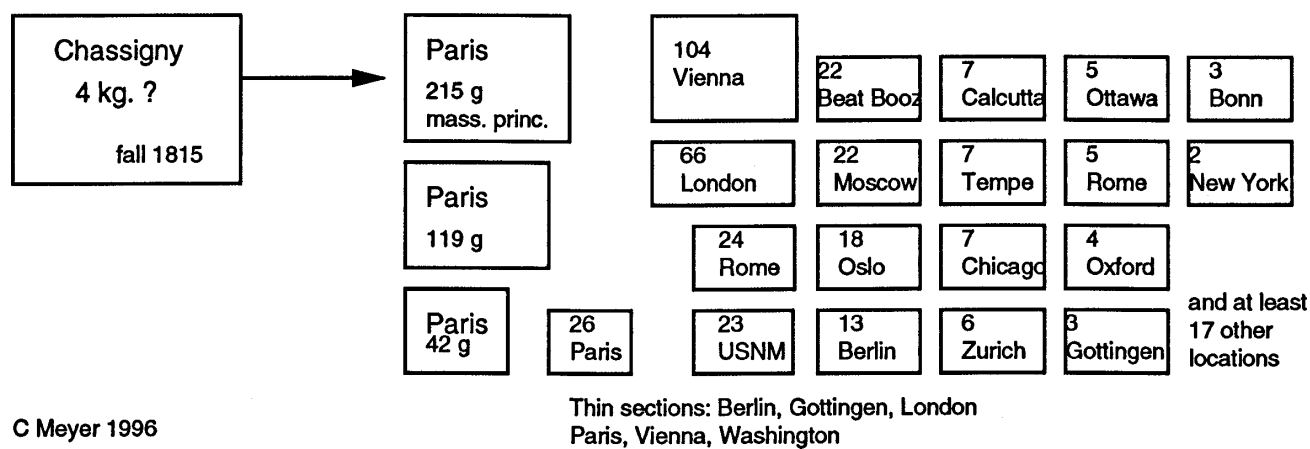
physical evidence for the invasion of Chassigny by aqueous fluids". However, the isotopic data for hydrogen is terrestrial, possibly due to isotopic exchange (see above).

### Processing

Although this meteorite apparently originally weighed ~4 kg., only a small amount of this unique rock is apparently available for research today (table I-3). The distribution of samples is given in figure VII-9. A dunite might be expected to have slightly different lithology in different places and each piece should be examined.



**Figure VII-8.** Normalized isotopic composition of Xe for Martian atmosphere trapped in EETA79001 compared with data for Chassigny. This is figure 3 in Swindle (1995), AIP 341, page 175.



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**Figure VII-9.** World location for remaining pieces of Chassigny meteorite.